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Flushing Spaces After Occupancy

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How long does it take after people leave a room before an acceptably low risk for airborne transmission? Here's how you can calculate it. I'll be using the following abbreviations in this post:

AC — air changes
ACH — air changes per hour
ft^3 — room volume in cubic feet

m^3 — room volume in cubic meters
CFM — air flow rate in cubic feet per minute
lps — air flow rate in liters per second
m^3/h — air flow rate in m^3 per hour
CADR — clean air delivery rate, either in CFM, lps or m^3/h

Empty Room Transmission

Airborne transmission primarily occurs indoors when in short range or when sharing a room with an infectious person. However, when an infectious person is in a room, respiratory particles they have exhaled can fill the room. If they leave and shortly after a susceptible person enters that room, they could still inhale a high dose of those particles and can get infected. Although this is not the most common mode of transmission, it is still a risk and cleaning the air in the space after they have left can mitigate this mode of transmission. It's called flushing the space.

How Quickly Does Flushing Remove Virus?

Air Changes (AC)
As explained in this post, every time you change the air in the space, there is a 63% reduction in the pollutant. The formula for total reduction of virus particles is:

% Virus Removed = 1-e^-(AC) (EQ-1)

For example, after 3 air changes, virus removed = 1-e^-3 = 95%

Air Changes per Hour (ACH)
The rate that the ventilation or filtration system can flush the air in a room is usually measured in air changes per hour or ACH which can be calculated as follows:

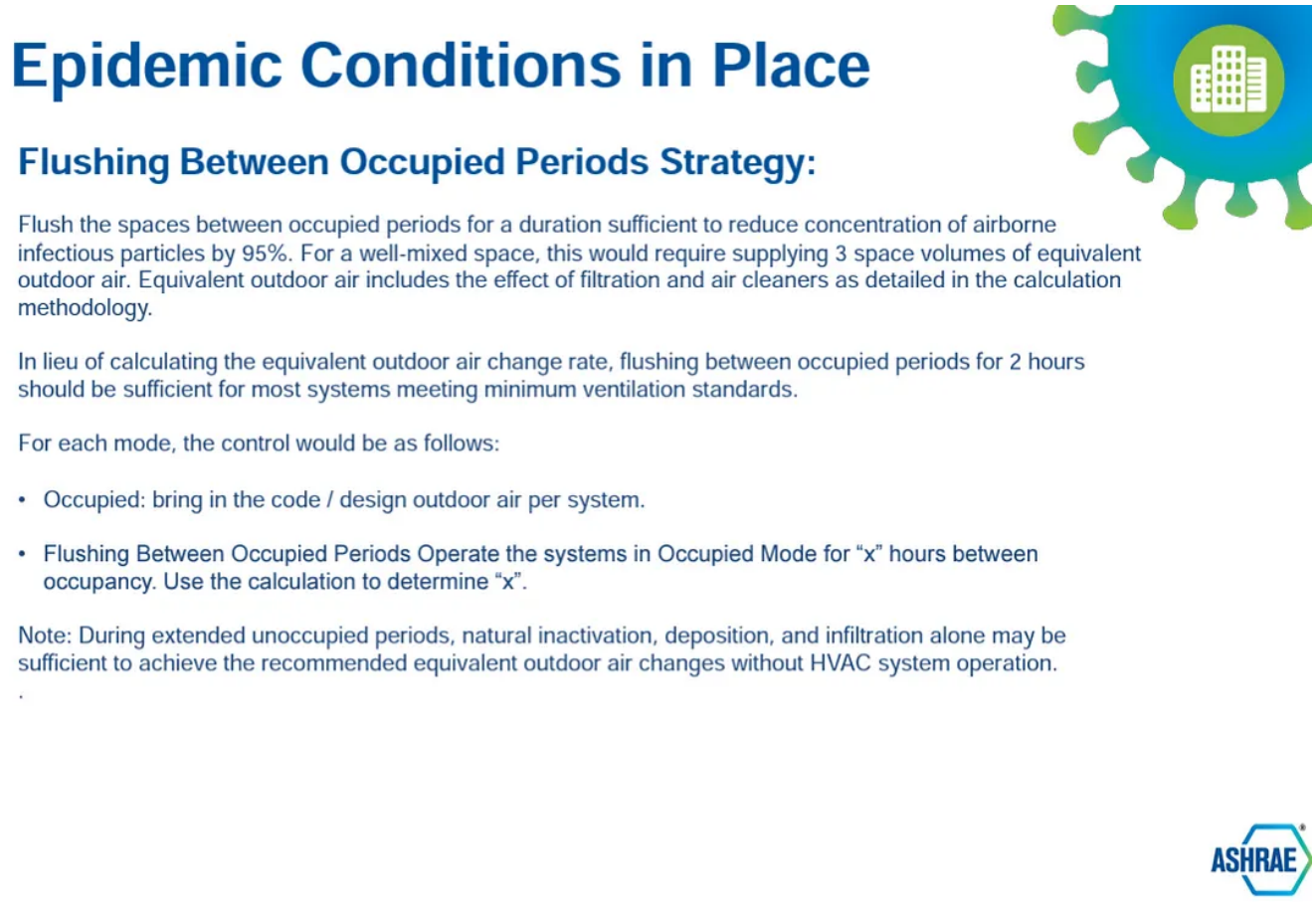
ACH = Clean air delivery rate x unit conversions / room volume (EQ-2) Where:
Room volume is in ft^3 or m^3 calculated as length x width x height
If CADR is in cubic feet per minute (CFM), the unit conversion is 60 minutes per hour.
If CADR is in liters per second (lps), the unit conversion is 3.6 m^3/h per lps.

Example: HEPA filter with a CADR of 200 CFM in a room that is 12 ft x 12 ft x 8 ft. What is the ACH?

ACH = 200 x 60 / (12x12x8)=10.4 ACH

How Much Flushing is Required?

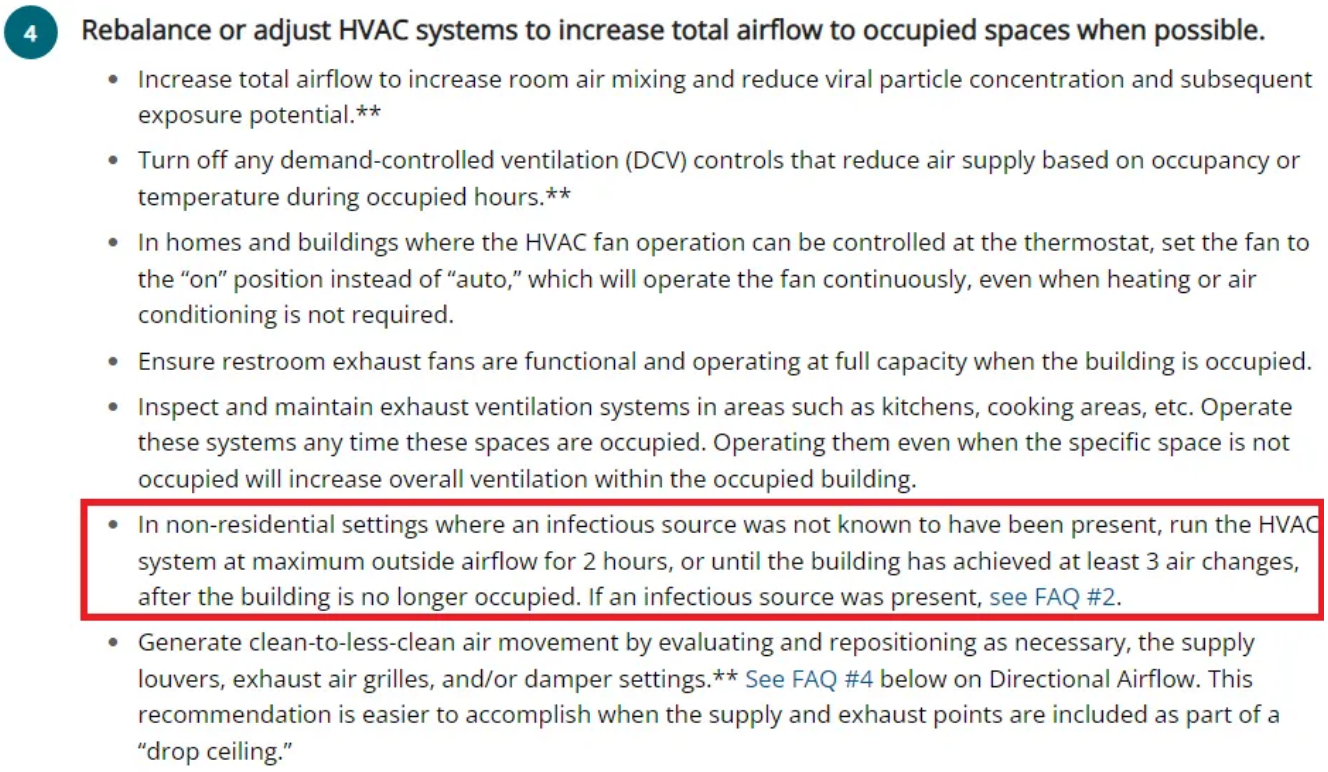
The guidance from the ASHRAE Epidemic Task Force indicates 3 air changes are required between occupied periods.


Epidemic Conditions in Place
Flushing Between Occupied Periods Strategy:
Flush the spaces between occupied periods for a duration sufficient to reduce concentration of airborne infectious particles by 95%. For a well-mixed space, this would require supplying 3 space volumes of equivalent outdoor air. Equivalent outdoor air includes the effect of filtration and air cleaners as detailed in the calculation methodology.
In lieu of calculating the equivalent outdoor air change rate, flushing between occupied periods for 2 hours should be sufficient for most systems meeting minimum ventilation standards.
For each mode, the control would be as follows:
• Occupied: bring in the code / design outdoor air per system.
• Flushing Between Occupied Periods Operate the systems in Occupied Mode for "x" hours between occupancy. Use the calculation to determine "x".
Note: During extended unoccupied periods, natural inactivation, deposition, and infiltration alone may be sufficient to achieve the recommended equivalent outdoor air changes without HVAC system operation.
ASHRAE

ASHRAE has also released a draft for standard 241 to control infectious aerosols. The draft also requires 3 air changes between occupancies.

The position of the CDC on their ventilation webpage is as follows:

- In general, flush for 3 air changes.



4 Rebalance or adjust HVAC systems to increase total airflow to occupied spaces when possible.

- Increase total airflow to increase room air mixing and reduce viral particle concentration and subsequent exposure potential.**
- Turn off any demand-controlled ventilation (DCV) controls that reduce air supply based on occupancy or temperature during occupied hours.**
- In homes and buildings where the HVAC fan operation can be controlled at the thermostat, set the fan to the "on" position instead of "auto," which will operate the fan continuously, even when heating or air conditioning is not required.
- Ensure restroom exhaust fans are functional and operating at full capacity when the building is occupied.
- Inspect and maintain exhaust ventilation systems in areas such as kitchens, cooking areas, etc. Operate these systems any time these spaces are occupied. Operating them even when the specific space is not occupied will increase overall ventilation within the occupied building.
- In non-residential settings where an infectious source was not known to have been present, run the HVAC system at maximum outside airflow for 2 hours, or until the building has achieved at least 3 air changes, after the building is no longer occupied. If an infectious source was present, see FAQ #2.
- Generate clean-to-less-clean air movement by evaluating and repositioning as necessary, the supply louvers, exhaust air grilles, and/or damper settings.** See FAQ #4 below on Directional Airflow. This recommendation is easier to accomplish when the supply and exhaust points are included as part of a "drop ceiling."

- In healthcare settings or places where an infectious person is known to have been present, flush the space for 5 air changes to have a 99% particle reduction.
- If there is a suspected case of measles, flush the space for 7 air changes to have a 99.9% reduction.

Although there are some highly contagious airborne diseases (like measles) where CDC provides specific guidance for 99.9% clearance wait times, the general recommendation in CDC's Guidelines for Environmental Infection Control in Health-Care Facilities is to wait to allow for a 99% reduction of any generated airborne particles before re-entering the room.

It appears to be a general consensus to flush the space for 3 air changes post occupancy in most settings. A more conservative value would be for 5 air changes or 99% reduction in virus concentration which the CDC recommends when there is a known case of an airborne disease or in healthcare settings. There also appears to be a consensus that in the absence of known air change rate from the ventilation system, assume a rate of 1.5 air changes per hour (ACH) and run the ventilation system for 2 hours after occupancy.

Calculating Flushing Time

Filtration

For portable air cleaning devices like portable HEPA filters, the clean air delivery rate should be provided by the manufacturer. When using high efficiency filters in an air handling unit, the clean air delivery rate can be calculated as the efficiency x the rate of recirculated air. An engineer or qualified professional would need to tell you the rate of recirculated air. The efficiency is given in ASHRAE 241P, Appendix A:

MERV	Efficiency (%)
<11	0
11	60
12	71
13	77
14	88
15	91
16	95

Ventilation

For mechanical ventilation rates, either an engineer or qualified professional can determine the outdoor air flow rate. Using windows does not produce a reliable level of ventilation which can vary greatly, so CO2 would ideally be used a gauge of the ventilation (see below).

Example: A classroom that is 30 ft x 30 ft x 9 ft has 250 CFM of outdoor air and 750 CFM of recirculated air with MERV-11 filters (60% efficiency). What is the air change rate? Using EQ-2:

ACH = CADR x 60/volume = (250 + 750 x 0.6) x 60/ (30 x 30 x 9) = 5.2 ACH

Calculate 3 Air Changes

Once you know the air changes per hour in the room, calculating three air changes is simple:

Time (hours) = # air changes / ACH
Time (minutes) = # air changes x 60 / ACH (EQ-3)

So if you have a room with 5 ACH and want to know how long to flush to achieve 3 air changes:

Time = 3 x 60/5 ACH = 36 minutes

CO2 — Calculating ACH

An alternative method is to measure the CO2 decay rate when everyone leaves the room. This assumes there is no CO2 generation in the room, either by people or though combustion. As explained here, you can use the following formula to determine the air changes per hour:

ACH = -1 x ln ((final CO2–420)/(initial CO2–420))/ time (in hours) (EQ-4)

For example, CO2 now is 1200 ppm. It initially was 1500 ppm and it took 20 minutes (20/60 = 0.33 hours). How many air changes per hour is the ventilation in the room?

ACH = -1 x ln ((1200–420)/(1500–420))/0.33 = 1 ACH

CO2 — Calculating Air Changes

An even easier way to use CO2 is to just measure the air changes by the pollutant decrease. The difference between the indoor and outdoor CO2 decreases by 63% with each air change, so 3 air changes gets you to 95% decrease (5% remaining):

Final indoor CO2 = (Initial Indoor CO2 — Outdoor CO2) x 0.05 + Outdoor CO2
Final indoor CO2 = 0.05 Initial Indoor CO2 + 0.95 Outdoor CO2 (EQ-5)

So if the CO2 starts at 1200 ppm, outdoor CO2 is 420 ppm and you open the windows,

there will be 3 air changes once the CO2 is:

Final Indoor CO2 = 0.05 x 1200+0.95 x 420 = 460 ppm

Absolute CO2 Levels

The truth is, percent reduction of a pollutant from an initial level is not the correct method of determining the risk of a space. The correct method is based on the concentration of the pollutant. If a space initially has a lower concentration of a pollutant, it will require a lower reduction in concentration to achieve the same level of risk as a space with a higher initial concentration. One method would be to pick a low CO2 level which would correspond to a very low level of rebreathed air. For example, if CO2 is below 500 ppm, you can assume that the space is very low risk. For reference, a steady state CO2 concentration of 500 ppm equates to approximately 60 liters per second per person, where ASHRAE 241 rates for control of infectious aerosols range between 10–40 liters per second per person in non-healthcare settings.

Air Mixing

One problem is that air might not be properly mixed throughout the space. If you are using a HEPA filter to flush the space, it might just be cleaning the air next to it and not properly cleaning the whole space. The CDC warns about this issue on their ventilation page. The easiest solution to ensure the air is properly mixed throughout the space would be to use a fan to circulate the air around the room. Placing HEPA filters in the middle of the room will also help.

When Flushing is not Required

The 3 air changes can be provided through ventilation or filtration, but they can also occur naturally through three processes:

Decay

Virus particles naturally decay over time and the rate often depends on temperature and humidity. With SARS-CoV-2, here are some values for the ACH due to decay:

- Based on DHS, half-life in most normal conditions is less than 2 hours. If it was 2

hours, that would be 0.4 ACH

- This calculator on line 330 estimates decay at 0.2 to 0.6 ACH
- This publication found 0.6 ACH for decay

Overall, an estimate of 0.4 ACH for decay is a reasonable value.

Deposition
Just like dust, particles can land on surfaces instead of remaining airborne. Once they land on a surface, you cannot inhale them and they pose no risk of airborne transmission, unless they are resuspended into the air. Deposition rates depend on particle size and other factors in the space. Some typical rates for deposition are 0.2 to 2 ACH (line 357) and it is estimated at 0.4 ACH.

Infiltration
Buildings are not air-tight. Air leaks in and out of the building, even if the ventilation is off and the doors and windows are closed. Typical values for infiltration are between 0.2 to 2 ACH, depending on how tight the building is.

Putting these together, it is reasonable to assume that combining infiltration, decay and deposition, the total natural air change rate will be greater than 0.5 ACH. This means that after 6 hours, the building will have 3 air changes without requiring any active flushing. Both the Ontario Society of Professional Engineers and ASHRAE 241 Draft state that if there is more than 6 hours between occupancies (like overnight), flushing the space is not required. This is important as running equipment for extra hours can have significant energy costs and if it provides little to no benefit, we should reduce energy consumption and spend our resources on more effective methods, like increasing the clean air delivery rate while the room is occupied.

Summary

- Flush spaces after occupancy for 3 air changes in most settings. Use 5 air changes if an infectious person was known to be present or in medical settings.
- Find the air changes per hour from ventilation and filtration. Time to flush (minutes) = # air changes x 60 / ACH

- If HVAC rates are not known, flush for 2 hours
- If the space will be unoccupied for 6 or more hours, flushing is not required
- Ensure the air is well mixed in the space when flushing

Indoor Air Quality | Airborne Transmission

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Written by Joey Fox

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P. Eng. HVAC engineer. I work on sustainability for building design and operations with a focus on building automation systems. Ensuring people get clean air.

Responses (1)

What are your thoughts? Respond

Deborahsantor
May 29, 2023

> lps — air flow rate in liters per second

Such a helpful post. It seems that this can be applied to many situations. Now I know that if I leave my HVAC for 2 hours on (MERV 13) after workers have left my house I can feel comfortable returning to the house. Before I had this information I... more

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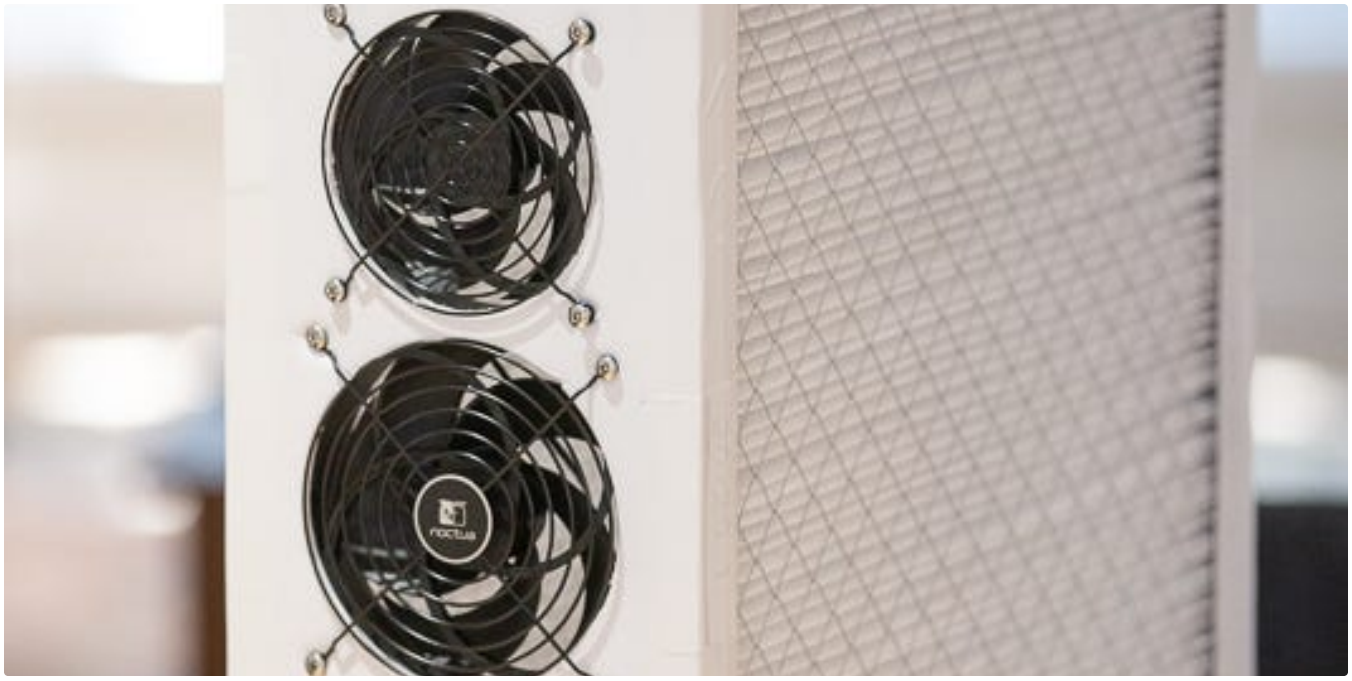

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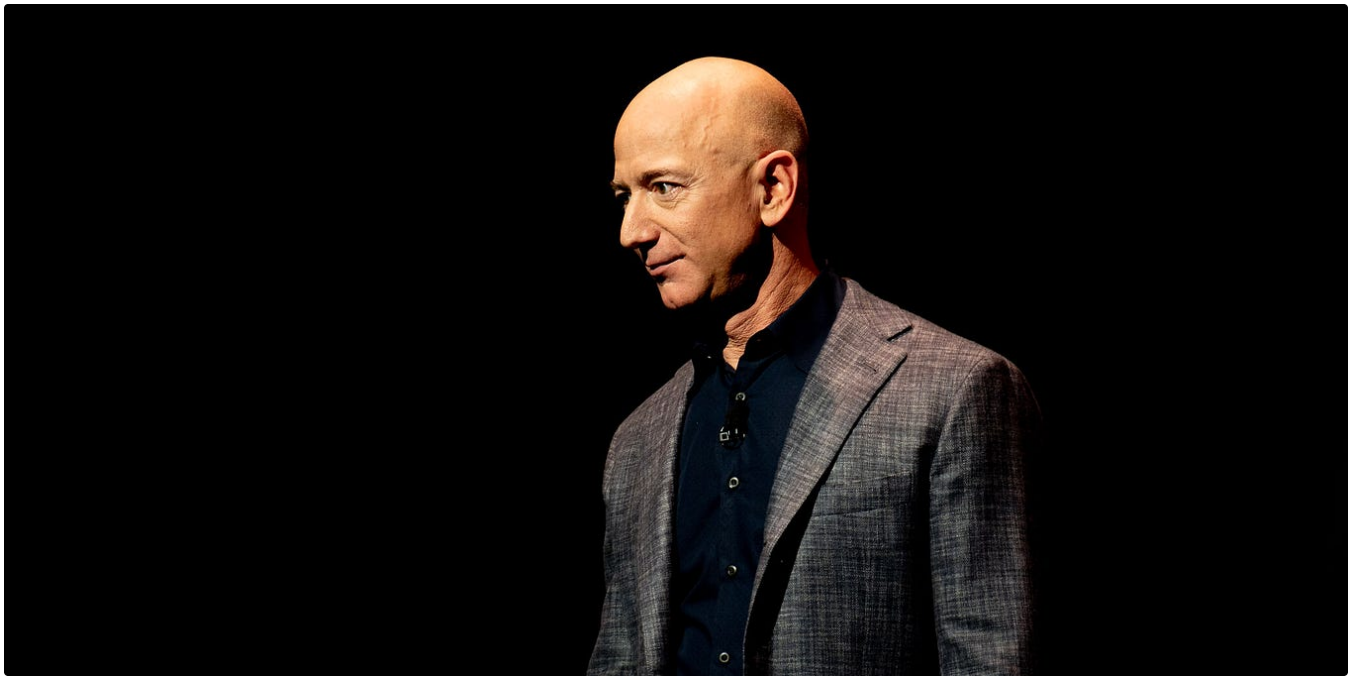

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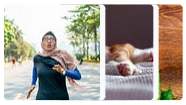

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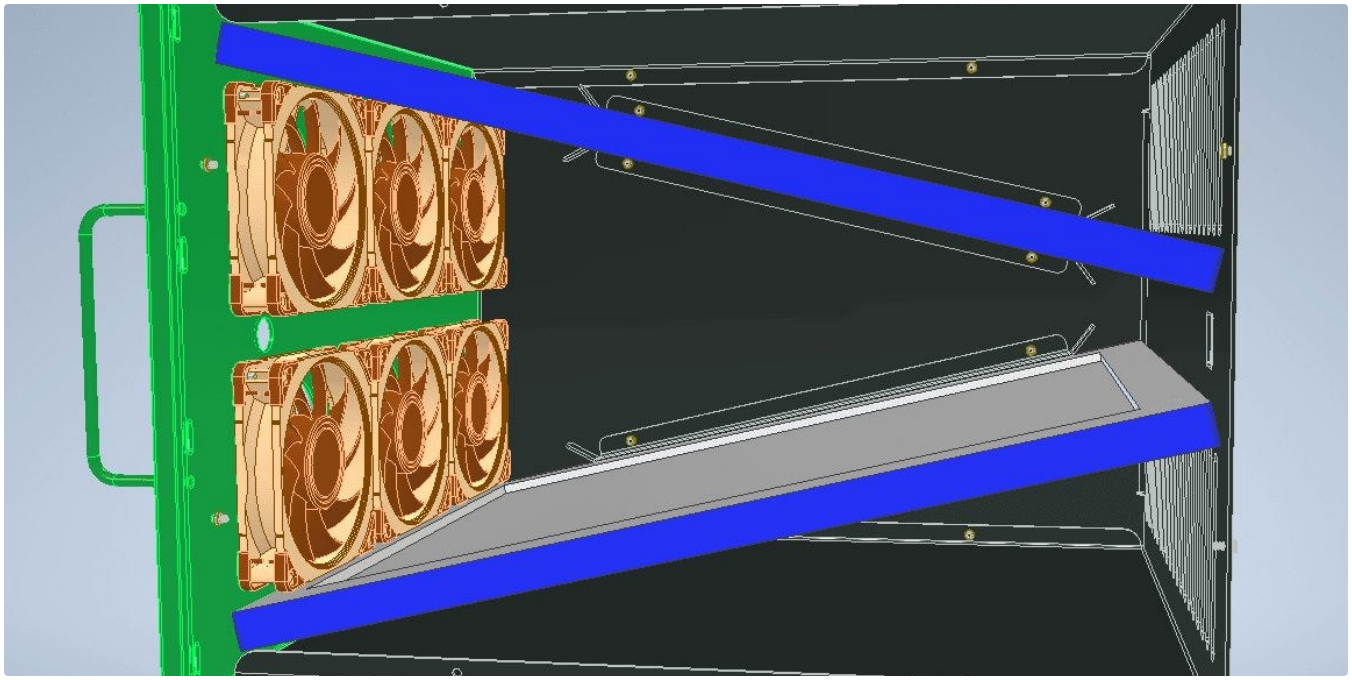

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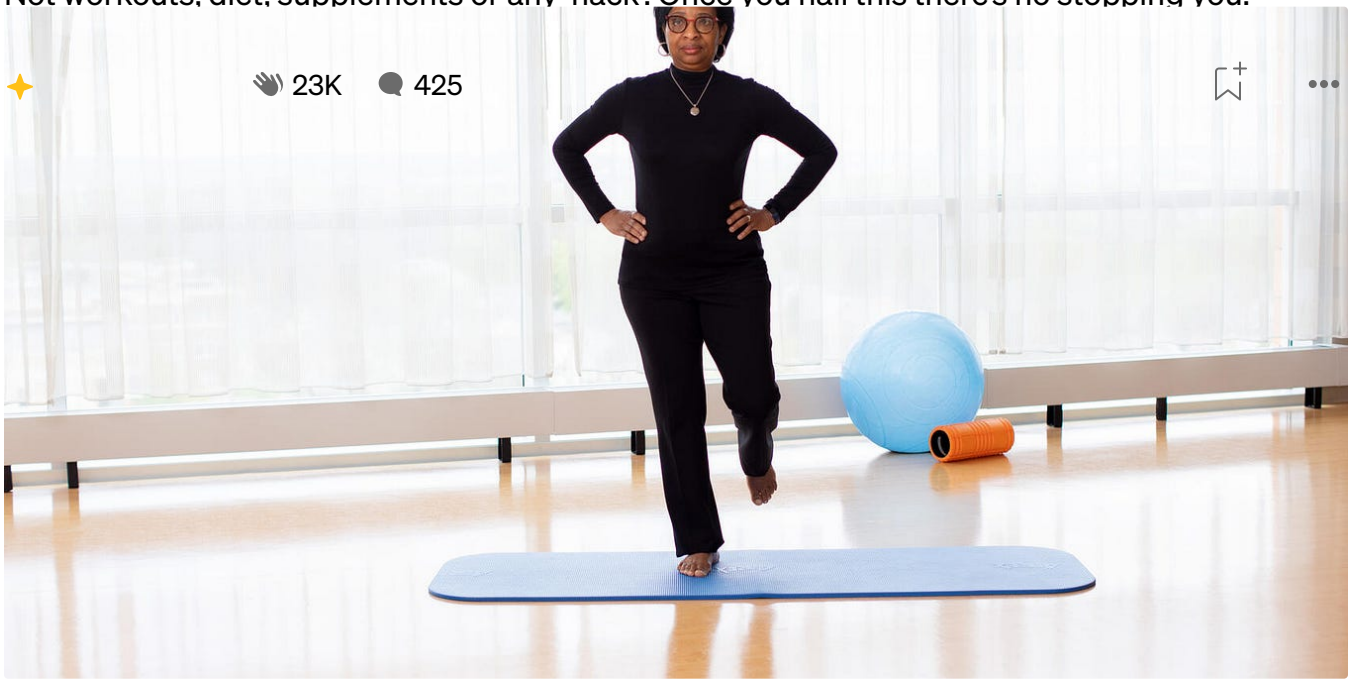

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